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SYSTEM ARCHITECTURE FOR A MILITARY WEAPON SYSTEM DEVELOPMENT PROCESS TO INTEGRATE DESIGN AND THE MANUFACTURING PROCESS FOR USE BY A GOVERNMENT TECHNICAL DEVELOPMENT AGENCY

by

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September 2014

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This thesis integrates Concurrent Engineering (CE) or Design for Manufacturability into a government research and development agency. For new weapon concepts originating within government, CE is difficult to apply effectively within the policies and bureaucratic structures. This project describes a proposed structure for a development agency, using fuzes and the U.S. Army Fuze Division as a basis.

Although the Fuze Division's application of CE to date has been effective, much potential remains unreachable due to the Department of Defense (DOD) acquisition policy, with its series of incremental design phases.

The proposed organization is arranged in teams according to professional/ engineering specialty. In addition, manufacturing engineering and fuze systems engineering groups are introduced. Integrated Product Teams managed by a member of the systems engineering group would draw from each of the specialized groups.

This project illustrates that an agency can be organized to support and promote effective concurrent engineering within the limitations of the DOD acquisition policy. With this structure, manufacturing considerations will be deliberately integrated into every new fuze design, at all design phases. Although current policy may not allow skipping a phase, the "Milestone B" fuze will now be functionally operational and manufacturable, greatly reducing the design work remaining for Milestone C.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARDEC	Armament Research Development and Engineering Center (Army)
CDR	Critical Design Review
CE	Concurrent Engineering
DARPA	Defense Advanced Research Projects Agency
DFM	Design for Manufacturability
DRT	Design Review Team (proposed)
FDC	Fuze Development Center (Army)
FDRB	Fuze Design Review Board (proposed)
GPS	Global Positioning System
IPT	Integrated Product Team
JCIDS	Joint Capabilities Integration and Development System
MEMS	Micro Electro-Mechanical Systems
PDR	Preliminary Design Review
RDECOM	Research Development & Engineering Command (Army)
RF	Radio Frequency
SDD	System Design and Development
SE	Systems Engineering
SMT	Surface Mount Technology

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EXECUTIVE SUMMARY

Currently, the development of a new specialized ammunition technology item such as a fuze takes too long, from initial concept through final production design, which is approved for fielding. As a rough order of magnitude, development of a "technology demonstration" (tech demo) fuze may require about five years from beginning until completion of sufficient testing to demonstrate that the new fuze is nominally capable of meeting performance requirements. At this point, after successful demonstration testing, the fuze design is approved to begin full-scale development—also known as "System Design and Development" (SDD). It is not uncommon for this SDD phase to require as much time as for the tech demo phase, or another five years. The reason for this simply stated is that although the fuze performance was successfully demonstrated, in order to be manufactured at high rates, much of the fuze's configuration must be significantly reworked to accommodate fabrication, assembly and manufacturing methods appropriate for production rates. Essentially, the entire fuze will be redesigned from the ground up during the SDD phase.

In order to facilitate a more efficient and effective design process, an organizational structure based on the matrix approach is recommended within the Fuze Division. This provides an environment to build effective product teams, while keeping functional groups together to establish and maintain several essential core competencies specific to fuzing technology.

The objective of this thesis is to propose an organizational structure through which a government design and development center can build and maintain the capability to perform concurrent engineering and integrate manufacturing and production engineering into the configuration of weapon systems, with fuzes selected as the example. Key challenges include developing a viable core competency in the area of manufacturing engineering, within an organization that does not actually manufacture any products. Also of interest is the requirement to conduct all fuze development according to and within the framework of the currently prevailing Joint Capabilities Integration and Development System (JCIDS) acquisition policy. The present structure

places an inherent emphasis on system performance requirements during the early phases of development, specifically during the Technology Development phase between Milestones A and B and also during the Engineering Manufacturing and Development period between Milestones B and C. During these phases, design reviews are arranged to require performance demonstrations in order to get approval (and funding) to proceed to the next phase of development. While prudent and necessary to protect the resources and financial interest of the Department of Defense and ultimately the taxpayer, manufacturing considerations are given minimal attention or simply "left out" when the main objective is to simply prove that a new design concept is feasible from an operational standpoint. It is interesting to note that even though the name of this phase actually includes the term "Manufacturing" most of the emphasis in reality is placed on engineering for performance and not so much on design for manufacturability. In fact, attention to manufacturing generally does not happen until the second half of this phase, after most of the work in the Integrated System Design half of the phase has been completed.

Short of completely revising the JCIDS process to specifically include manufacturing engineering up front, this effort explores the use of organizational structure as a means of building manufacturing engineering into the normal process of developing a new product such as a fuze.

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I. INTRODUCTION

A. BACKGROUND

In the early 2000s, the Army's Research Development & Engineering Command (RDECOM) identified the need to develop in-house prototyping capabilities for several key technology areas deemed critical to defense systems. As a result, senior management allocated budget to initiate the Manufacturing Enterprise effort under which specific categories of technology were reviewed. Fuzes were among the items presented by a team including the author, and subsequently identified for which such prototyping capabilities were deemed essential. As a result, the Army's Armament Research Development and Engineering Center (ARDEC) established the Fuze Development Center (FDC) at Picatinny Arsenal, New Jersey, for the purpose of providing a capability to design and build prototype fuzes and related components suitable for operational testing. As the FDC was in the process of being stood up, an apparent gap in ARDEC's capabilities relative to fuze development began to emerge–specifically the challenge of taking a new fuze design and efficiently transforming it from a working prototype to a configuration suitable for mass production (Redington 2010).

ARDEC has a long-established and continues to maintain a talented and proven pool of technical expertise for all levels and all types of fuze design. Over the years, the ARDEC Fuze Division has originated numerous highly successful fuze design concepts. Additionally, within the fuze industrial base, several contractors have proven capabilities with regard to full scale engineering and manufacturing development of fuzes.

The so-called gap is found in the transition from a fuze that works (technology demonstration, commonly referred to as "tech demo") to a fuze that is economical to manufacture. With fuze technology becoming increasingly complex, the process to develop a new fuze from concept to working prototype requires many years due to factors such as long lead times to design and produce a single custom electronic chip. Upon successful completion of a tech demo, the fuze design then moves into the system design

& development (SDD) phase, which generally requires several more years before the fuze can be released for production and fielding to the Warfighter.

The net result is that the current practice is to begin with a concept development phase that focuses all resources and brainpower toward the goal of demonstrating performance, meaning that it is possible to build a fuze that is capable of providing the specifically-defined desired operational functions. As such, the design, prototype and testing segments are all executed with the goal of minimizing time; cost and materials necessary to perform the immediate task at hand (e.g., build only a minimal quantity of prototype hardware necessary to run a test to verify performance).

This thesis describes the current fuze development process and some of the specific areas related to manufacturing design. It explores in detail how to build a system architecture for the fuze development organization to deliberately integrate the manufacturing process into the entire design process from the beginning, starting with initial concept.

If successful, the system architecture will drive the design team to deliberately design-in features from the ground up that are geared toward manufacturability. The result of which would deliver a complete fuze ready for production immediately after the first successful design-build-test cycle is complete. Ideally, this would translate into merging the tech demo and manufacturing development phases together into one phase within a timeframe normally needed for one phase. The potential cost savings would be significant in terms of dollars and overall time required for fielding.

B. PURPOSE

The purpose of this thesis research is to propose a system architecture that is designed with the specific purpose of ensuring that manufacturing process is included and accounted for from the very beginning of a fuze development effort. This thesis is designed to be widely applicable among many classes of weapon systems. While concurrent engineering is a generally accepted practice among the industry leaders in the commercial world, it would appear that although the Department of Defense claims to support the concept, the organizations are generally configured based on historical traditions such as forming groups to handle specific classes or families of weapon systems. For example, the ARDEC Fuze Division has generally been divided into a group for artillery fuzes, another for mortar fuzes, grenade fuzes and so forth. This approach has served well and has resulted in many exceptional fuzes over the years in terms of being capable of meeting demanding performance requirements. However, with available fuze technologies becoming more complex during recent years, the fuze designs have followed the trend and become much more complex as well. As such, development times have become longer, while at the same time, continually evolving mission needs have given rise to new operational requirements rapidly emerging from multiple combat theaters, with the demand to meet these requirements as quickly as possible.

It is worth noting at this point that the ARDEC Fuze Division also includes several groups devoted to advanced research aimed at developing future fuze technologies. For the purpose of this study, only the parts of the organization that support the development of specific fuzes are being considered in an effort to clearly present an organizational structure that is designed for product development.

Fuzes have been selected as an example of a specialized class of weapon system that can be used that cite specific attributes that illustrate the utility of this thesis. A fuze is defined according to The U.S. Army Materiel Command's Engineering Design Handbook Ammunition Series Fuzes (November 1969) as:

> A device with explosive components designed to initiate a train of fire or detonation in an item of ammunition by an action such as hydrostatic pressure, electrical energy, chemical action, impact, mechanical time or a combination of these. (G-3)

The primary function of a fuze is to detect a "valid target" and then reliably initiate an explosive train to detonate the ammunition item. The target sensing functions available include a range from simple to extremely complex, including basic impact, to electronic proximity sensors, to specific target signature recognition devices.

In addition to the basic function of initiating the detonation of ammunition, modern fuzes must perform a safety role to prevent unintentional detonation to minimize the hazard to the Warfighter. This is typically accomplished by providing a mechanical separation between sensitive, limited output primary explosive and the secondary, less sensitive high explosive components.

C. RESEARCH QUESTIONS

- What organizational structure(s) have been used successfully by private sector manufacturing firms?
- For a government design and development organization, how can an organizational structure be designed to deliberately promote the integration of manufacturing into the product development process?
- What does the proposed organizational structure look like? How does it improve upon the established organizational structure?

D. BENEFITS OF THE STUDY

This thesis provides a suggested organizational structure for a government design and development agency that will facilitate the integration of manufacturing and production engineering into the complete product development cycle. If implemented and properly managed, an organization such as the U.S. Army's Fuze Division will be able to significantly reduce the time required to field a new weapon system such as a fuze. This thesis will provide a basis of knowledge that can be used directly by U.S. Army ARDEC, and leveraged by other military related activities; in order to establish a system architecture for an organization with the mission to more effectively develop precision weapon systems, by incorporating the development process along with the manufacturing process.

E. SCOPE

The thesis focuses on a system architecture or structure that can be put in place and used to guide the development process for any type of fuze to ensure that producibility is intentionally designed in up front, rather than added on top of an already-established design afterwards. This thesis is focused on fuze design, for the benefit of using very specific examples and information to illustrate certain points. However, it is intended to be of interest and applicable to a range of government design and development agencies, specifically those involved with other specialized classes of weapon systems and components.

A brief description of the concurrent engineering practices currently in effect at the FDC is provided as a point of reference. Following said description; successful CE approaches from Industry are reviewed to understand what was done from an organizational structure standpoint to facilitate the adoption of CE into the normal routine and culture of various firms.

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II. FUZE DEVELOPMENT CENTER OVERVIEW

A. INTRODUCTION

During the relatively short time that the Fuze Development Center (FDC) has been in operation, several new designs for fuzes and fuzing components have been designed and produced, with successful results based on the author's direct involvement.. The FDC was conceived to operate in a similar manner as small business, albeit within the constraints of being a government-owned and operated organization. (Author participated on team that developed this approach.)

The facility has been fitted with manufacturing and production equipment necessary to support all aspects of fuzing. The underlying purpose is to demonstrate that a given fuze design can be manufactured with commercial equipment normally available to a typical fuze contractor.

That being said, as the FDC was made available to the fuze engineering community, it rapidly became evident based on the direct observation of the author, that the practice of design for manufacturability is a concept that design engineers seem reluctant to embrace. Although most engineers will readily agree that design for manufacturability is valid in principle, the actual practice is quite different. Faced with the pressure of producing a new fuze design, usually with less than optimal funding, limited availability of technical personnel and time, there is a perception that manufacturing engineering is not essential at this time. As such, phrases such as "we just need to get this fuze to work right now," "we can worry about producibility later," or better yet, "leave that to a contractor, since they are the manufacturing experts" are used to justify focusing all efforts to designing for mission-related primary performance characteristics only, again, based on the author's experience.

Additionally, engineers tend to segregate themselves into specialties, such as electronic circuit design, or mechanical design. In the world of fuze design, these are further divided into highly specialized areas of expertise such as proximity sensor design, Global Positioning System (GPS) sensors, Micro Electro-Mechanical Systems (MEMS) and so forth. Many consider “manufacturing engineering” to be a separate specialty to be performed by another engineer, and usually at a later time, because there is no sense in wasting valuable engineering time to streamline the design of a component that may not meet performance requirements and then needs to be redesigned or even abandoned based on the author’s experience and multiple conversations with colleagues. .

Because manufacturability of a military product such as a fuze is not regarded as a performance requirement, it is subconsciously or even deliberately given a lower priority than other classical performance requirements considered to be common knowledge among the fuze community, such as explosive train reliability, radio frequency (RF) signal strength, proximity sensor target recognition, impact survivability, material strength and so forth. At this early point in the design process, manufacturing is largely regarded as a distraction that serves no immediate use, but only interferes with the priority of making the fuze work.

This is unfortunate, because beyond the traditionally recognized high-cost tradeoff items like molded vs. machined parts, there are numerous more subtle opportunities for a design to facilitate production with little or zero cost added. One such example of a zero-cost design feature is including a set of reference markings (known in the trade as “fiducials”) on a printed circuit board (Stephen Redington, personal communication). A fiducial is an index mark (typically a solid circle), made of the same copper material as the conductive tracks on the circuit board, which is used by the optical sensors on automated surface-mount assembly equipment to index and set the location of all the electronic components. The addition of fiducials to the artwork of a circuit board literally costs nothing to include, but without them, automated equipment cannot be used for assembly without requiring either a revision to the board design or additional programming time to search for features on the circuit board that might be sufficiently recognizable by the optics to establish suitable reference (Stephen Redington, personal communication). For hand-assembled experimental circuits, there is no need for such markings, so a design engineer has no reason to even think about including them on his/her design, which means that even if the experimental circuit performs perfectly, a design revision will still be necessary, if only to add two “spots” per circuit card to allow for automated assembly.

In the past, the practice of deferring manufacturing engineering to later did not seem to affect the ultimate success of a fuze development program. However, fuzes were mainly mechanical devices, with limited electronics on board, and the transition from prototype to production was fairly well understood. Modern fuzes are complex electro-mechanical devices designed for missions with demanding performance requirements, including proximity function with sophisticated electronic anti-countermeasure features built into the RF signal. One of the unpredictable side effects with precision electronics that is considered common knowledge among those involved in electronic design, is that the performance of a circuit can be affected simply by changing the physical location of components. This alone is reason for concern when a proven prototype fuze configuration is revised to improve producibility, particularly if physical layout of the circuit must be changed to facilitate assembly.

In addition, the prevailing Joint Capabilities Integration and Development System (JCIDS) project management process for DoD acquisitions tends to emphasize schedule and performance and focus on acquisition cost, during earlier phases of development based on the author’s experience and multiple conversations and interactions with colleagues. . Again, because manufacturing/producibility engineering tends to add significant immediate cost, with no discernible (immediate) benefit, this is unfortunately an easy cut for a project manager to make, especially when under threat of program delay or cost growth or budget cutbacks.

B. CURRENT PRACTICES

Within the FDC, as a new fuze or fuze component design is developed, a spiral development process is utilized. The FDC process is similar to and based upon the “spiral –to-circle” model used by Industry and described by Maier and Rechtin (2002). Figure 1 shows a highly simplified map of the process as normally executed in a government product development program. The grey oval at the left represents the technology demonstration phase typically performed by the government, with the output being in the form of a conceptual design along with a contract to perform final manufacturing design.

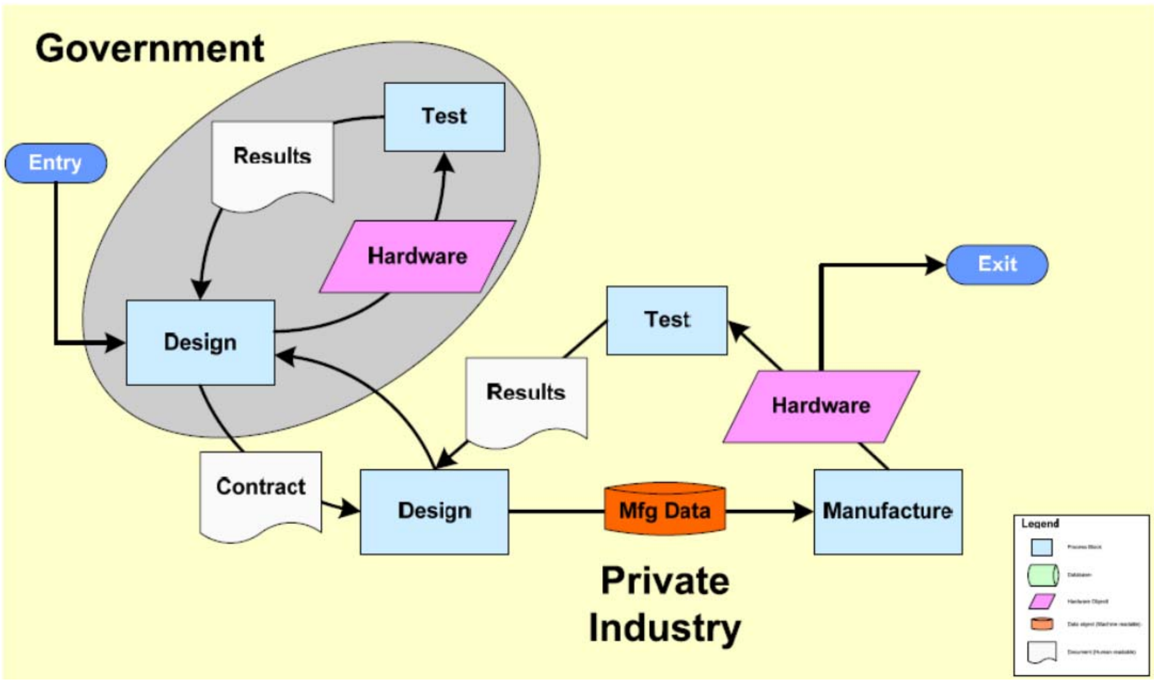

Figure 1. Simplified Government / Industry Design & Development Process (from Redington 2010)

At that point, a contract is developed to manage the transfer of design requirements to a defense contractor, who takes the concept and essentially repeats the development cycle represented by the triangle in the process map diagram, with the development and addition of manufacturing data to be incorporated into the final product design. It is noted that the primary output and objective of the current practice is focused on the end item hardware, or the design of the fuze itself, with a result that many of the manufacturing process details remain within the contractor as proprietary or trade secrets.

Figure 2 shows the format of the design process as adapted and currently in use by the FDC (Redington 2010). For fuzes and fuzing components developed within the FDC, the normal process has been streamlined by essentially merging the two cycles into a single cycle that incorporates manufacturing processes into the development process. A notable difference is that the primary output of this FDC development process is the manufacturing data, instead of the design of only the fuze hardware, as shown in the traditional approach.

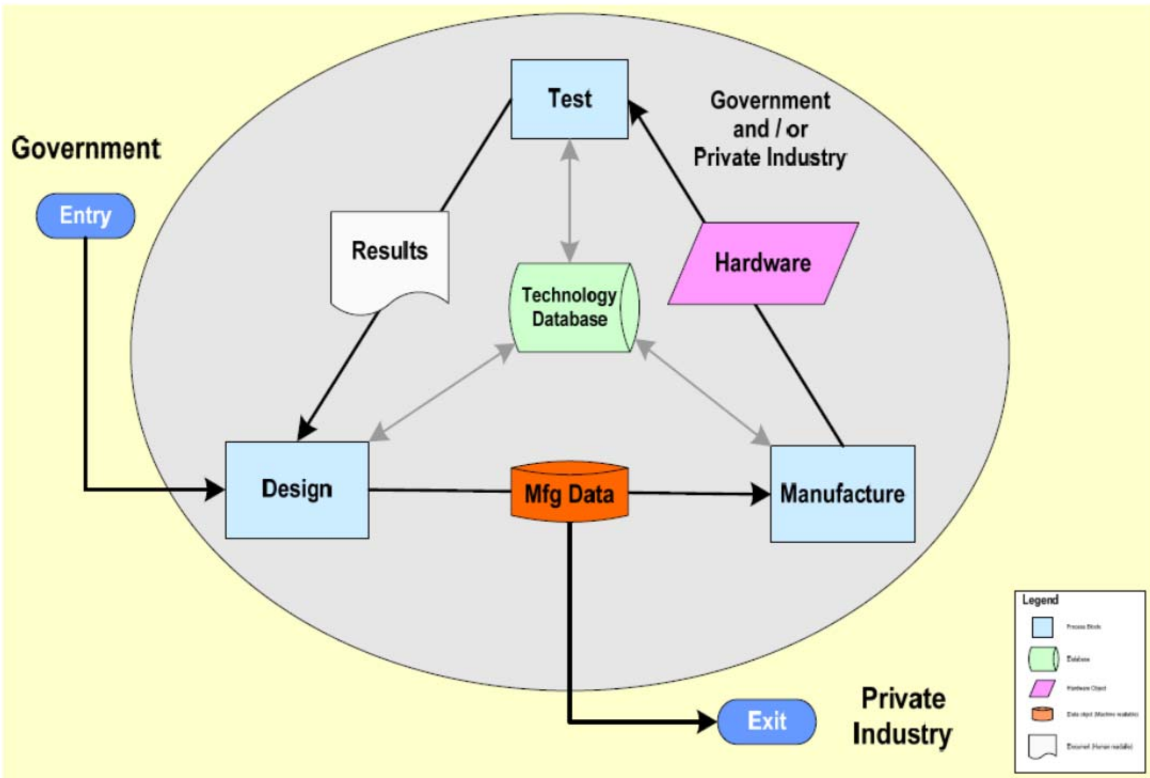

Figure 2. Design & Development Process Used by ARDEC Fuze Development Center (from Redington 2010)

This set of manufacturing data will include the usual technical data such as drawings and specifications, along with comprehensive descriptions of all manufacturing processes that were developed concurrently with the fuze. This complete set of information can then be transferred to any capable fuze contractor, with a high probability of success in production of the new fuze. A corollary benefit is that the new fuze design now comes with a documented and demonstrated manufacturing process, which makes it difficult to defend a claim that the new fuze design cannot be produced.

This process is modeled after current product development practices used by industry. To date, the FDC has used this process quite effectively to manage the design of fuze components such as electronic circuit assemblies. A more detailed process specific to managing the development of circuit card assemblies used by the FDC is shown in Figure 3. It is noted that since its inception, the FDC has not yet been given the opportunity to become involved in any complete "start-to-finish" new fuze development programs which are few and far between.

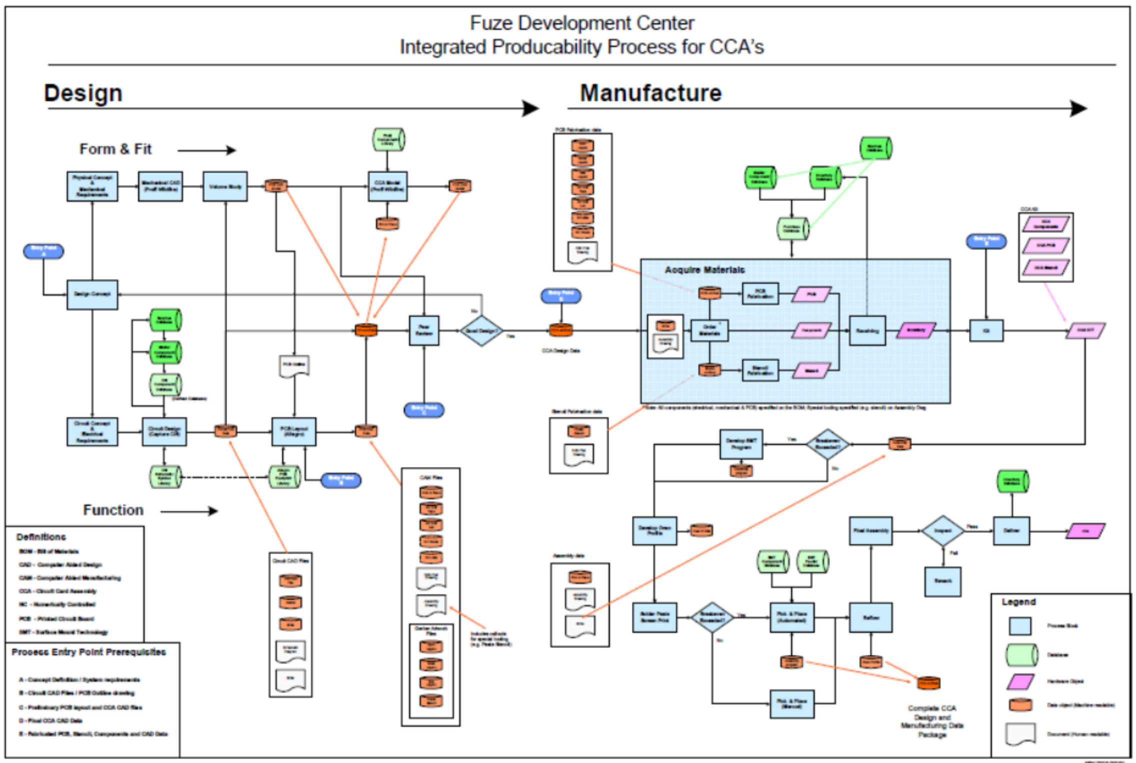

Figure 3. ARDEC Fuze Development Center Detailed Process (from Redington unpublished)

Beyond the FDC, the larger Fuze Division remains more or less traditionally structured in that branches or teams consist of groups of engineers assigned to similar fuze types based on end item (e.g., artillery, mortars, grenades).

C. BENEFITS

The benefits to the FDC's current practice have been realized to some degree already. For some projects, the turnaround time has been radically improved. One example of a success story is that of a small supplemental circuit that was designed by another agency for use as a performance upgrade to an existing, currently fielded tactical missile system. The design was presented to the FDC, and FDC engineering staff reviewed the design, recommended and made a few minor modifications and completed the design. At the initial meeting, a circuit design was presented that included all components laid out on a square printed wiring board (PWB). During the discussion, drawings for another design on a circular PWB were noticed. Upon further inquiry, it was explained that the square design was intended to verify circuit performance, and the circular design was the same circuit, configured to fit into the available space inside the missile. The FDC engineering team immediately recommended starting with the round design, on the assumption that if it functioned properly, that would completely eliminate a second iteration. So the decision was made to produce the prototype circuit to production specifications.

Then a sample production quantity was run, basic testing of this circuit assembly was performed (successfully) and the working components were delivered to the (Army) customer all within two weeks from the date of the initial meeting, for which the simple decision to begin with the final design configuration easily eliminated at least two weeks from the overall turnaround time (Stephen Redington, personal communication).

However, this current practice of bringing a more or less completed design to the FDC has also brought to light some of the problems and inefficiencies that are due to the "old way" of conducting business. Even though it can be painful at the time, the discovery of bad news can be beneficial, because the issues can only be addressed once they have been made known.

One such issue is the understanding that the FDC resources can add the most value when engaged early in the design process. A common scenario involves a group of engineers showing up at the FDC with a "box of parts" collection of new and custom fabricated parts such as printed circuit boards, and Surface Mount Technology (SMT) components with the idea of using the automated assembly equipment to save some time and money. However, at this point the design is already established and may actually interfere with the ability to effectively and efficiently set up and run the product through the automated assembly line.

Although much progress has been made since the establishing of production prove out capabilities at the Fuze Development Center, there is still no formal strategy to define when and how to incorporate the resources such as the FDC into the design process, based on the current practice as observed by the author. This thesis is an approach to provide an organizational layout that is conducive to effectively integrating design for manufacturing into the normal routine for development of new fuzes.

III. RESEARCH ANALYSIS

A. INTRODUCTION

This chapter describes a review of concurrent engineering design practices, in general. More significantly, the current practice within the ARDEC Fuze Division, and in particular the Fuze Development Center is described as well. Of particular interest is the application of concurrent engineering practices within the FDC, which has recently begun to incorporate some basic design for manufacturing principles into its standard routine.

B. CONCURRENT ENGINEERING

In order to develop a useful, approach to effectively incorporate concurrent engineering into an organization, it is helpful to understand the concept of CE along with how the organization has utilized CE to date. This section includes a brief overview of CE along with a summary of CE as practiced by the FDC.

1. Review of Concurrent Engineering Design Practices

Throughout Industry, the practice of concurrent engineering is widespread and generally accepted as a “best practice” among successful commercial entities engaged in the design and development of technologically complex products intended to be produced and sold to customers.

Although many definitions can be found, the practice of Concurrent Engineering (CE) is essentially defined as “a systematic approach to creating a product design that simultaneously considers all elements of the product life cycle, from conception through disposal, to include consideration lf manufacturing processes, transportation process, maintenance process, and so on.” (Blanchard and Fabrycky 2006). Instead of simply designing first to meet basic operational performance requirements, the practice of CE requires that later phases of the life cycle, such as production, maintenance and end of service life disposal, must be taken into account up front.

Concurrent engineering, described by Anderson “is the proactive practice of designing products in multifunctional teams with all specialties working together from the earliest stages” (Anderson 2010).

According to Ranky:

> Concurrent Engineering is very much a team management, people, communications, sound technology and a “culture” issue. It is about thinking of the “total design and manufacturing cycle” and implementing it using appropriate (not necessarily the latest) technologies and excellent people equipped with multidisciplinary skills… The heart of the problem is that engineers in design, manufacturing, quality assurance and maintenance do not speak the same language. Most obstacles are cultural and organizational. (1994)

And in 1987, the Defense Advanced Research Projects Agency (DARPA) generated a definition as well:

> Concurrent Engineering is a systematic approach to the integrated concurrent design of products and their related processes including manufacturing and support. This approach is intended to cause the developers from the outset to consider all elements of the product life-cycle from conception through disposal including quality, cost, schedule and other user requirements. (Backhouse 1996)

Although $60 million was spent, Backhouse observes that the DARPA effort failed to explain the need for CE (Backhouse 1996). It is reasonable to suggest that the same economic forces behind the trend of private firms drive toward CE represent a valid need for CE within the government community. However, economic viability being an essential element to the survival of private firms, it is not surprising to find that the pursuit of CE has been given high priority among the private sector. Unfortunately, among the government community, CE may only be pursued as long as it remains a management focus area, with little immediate negative consequence for failing to fully incorporate CE into the normal routine and accept CE into the prevailing culture.

CE provides an effective means of pursuing design simplicity. Huthwaite cites Henry Ford’s quote as follows: “My constant effort is in the direction of simplicity. Complexity is the enemy. Nearly everything we make is much more complex than it needs to be” (2007).

A significant part of CE is the concept of Design for Manufacturability (DFM), which is described by Chiang and Kawa, as follows:

> Design for manufacturability (DFM) in its broad definition stands for the methodology of ensuring that a product can be manufactured repeatedly, consistently, reliably, and cost effectively by taking all the measures needed for that goal starting at the concept stage of a design and implementing these measures throughout the design, manufacturing, and assembly processes. It is a solid awareness that a product's quality and yield start at the design stage and are not simply a manufacturing responsibility. (2007)

DFM is also defined in more detail by Anderson as "the process of *proactively* designing products to: (a) optimize all the manufacturing functions: fabrication, assembly, test, procurement, shipping, service, and repair; (b) assure the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction; and (c) ensure that *lack of* manufacturability does not compromise functionality, styling, new product introductions, product delivery, improvement programs, strategic initiatives, and unexpected surges in product demand" (Anderson 2010).

Economics is the primary motive behind the widespread acceptance of CE among the commercial world. In short, CE works. It allows for a much shorter design cycle, with products such as cell phones and smart devices moving from concept to production-ready in three to six months. Many firms, driven by economical need have embraced CE as a matter of survival, but in doing so have greatly improved their products but also the capability of their organizations to rapidly and reliably develop new products.

A multi-functional or cross-functional team approach to design is the key element of successful CE implementation. As per analysis presented by Ng and Jee, of a Malaysian semiconductor manufacturing firm,

> …it is apparent that the firm's product development team consist of cross-functional engineering teams that work together in order to achieve better performance in their projects. Due to the cross-functional nature of these teams, employees from different departments require to have regular progress review meetings so that all functions involved can gather together and contribute their ideas or concerns on the project. (Ng and Jee 2013)

Perhaps even more important is the idea of early active participation by all members of the multi-functional teams. Ranky states "Every important design decision must be considered with great care at the earliest stage by a team of: Designers; manufacturing engineers, marketing experts, quality and maintenance engineers as well as the key customers" (Ranky 1994).

Beyond the composition of the team itself, the concept of teamwork is essential. Prasad states "Teamwork cross-pollinates teams' ideas and gives members of a work-group a better understanding of their approach and methods of common problem solving on the whole project" (Prasad 1996).

2. Review of Concurrent Engineering Practices at ARDEC Fuze Development Center

From the start, FDC engineers have incorporated concurrent engineering principles into their design process to the greatest extent practical. This has worked fairly well for projects on which the FDC has been given control of the development process, and particularly where the FDC has been involved very early in the design process. Difficulties tend to arise in a typical situation where the FDC is requested to develop an assembly process for an electronic assembly, using circuit boards that have already been fabricated. This is the sort of situation that occurs when design engineers do not fully understand the concept of concurrent engineering. For example, a design engineer (or group) acting in good faith, comes up with a circuit design, and then extensive bench testing is performed and completed to prove it works. Then, in an effort to keep the process moving forward, the engineer(s) decides to take the next step of designing circuit boards and then getting them made. Now, with all the components in hand, the design team decides to take advantage of the automated assembly capability at the FDC, and asks for their help.

At this point the FDC team is forced to work with the components provided, which greatly limits the flexibility in optimizing an assembly process. For the example of an electronic assembly, there are many factors to consider when selecting components for automated assembly.

Besides the physical configuration of the parts, many components are available pre-packaged for automated assembly (on reels for high quantities or sticks for smaller quantities). Furthermore, many components such as connectors may be completely eliminated by changing the configuration of the circuit board itself. The use of a rigid-flex type of circuit board typically results in a significant reduction or the complete elimination of interconnects between boards, with the added benefit of greatly improving performance (reliability) by removing a usual source of failure, and also cost savings by reducing parts count and optimizing the required assembly time.

C. RESEARCH

Research for this thesis was conducted, which consisted of a literature review in search of any work that may have been done to address the role of concurrent engineering relative to government product development projects.

1. Literature Review

A literature search was performed, but no significant information was found specifically relating the incorporating of concurrent engineering into practice within the framework of a government-owned research and development enterprise. As such, this thesis will describe a proposed structure to facilitate and encourage the integration of concurrent engineering into the DNA of an organization's operational structure. However, looking beyond the realm of government agencies, many private-sector firms have experienced success with adopting concurrent engineering. In many cases, effective implementation of CE necessitated the evaluation and re-working of management and organizational structures. Some key examples of organizational structuring to accommodate CE are discussed below.

A key factor or possibly *the* key factor in successful implementation of CE is the establishment of effective teams, and then providing an environment conducive to teamwork. Ranky describes teamwork as follows: "…designers, manufacturing engineers, marketing personnel, quality and maintenance engineers and the customers work together to achieve joint success. …we need more freedom, more openness, better overall communication and understanding between all those involved in developing the product" (Ranky 1994).

According to Anderson, early forming of "complete teams" is essential for success. It is beneficial to include vendors on design teams to allow them to participate in the design of components and parts that they will end up building. Also, Anderson indicates it is useful to include "non-technical" team members such as marketing (to represent the voice of the Customer) as well as purchasing personnel to work with vendors to establish partnership relationships and also to pre-qualify parts (Anderson 2010).

The apparent industry standard has most successful firms utilizing some form of matrix management structure to coordinate project teams made up of personnel from multiple disciplines (Backhouse 1996). Backhouse identifies four variants of management structures ranging from functional to dedicated project teams. Diagrams for each are shown in Figure 4. In addition to the basic "functional" organization, the other three are forms of matrix structures, with varying levels of emphasis on the project or product teams. Backhouse notes that CE has been a significant influence in driving companies from traditional functional structures, toward a matrix-based approach. Backhouse observes a learning-curve effect among firms that have re-organized along project-based teams as follows:

> However, experience has shown that companies which have moved directly from a functional organization to a project-based structure have, over time, actively moved to reintroduce some of the elements of functional structure. Frequently the requirement for this is to ensure long-term retention of skilled people through the provision of an identifiable location within their peer group. The undoubted benefits of pure project-based structures bring with them certain long-term deficiencies which can only be eliminated by some form of management matrix which includes a functional element. (Backhouse 1996)

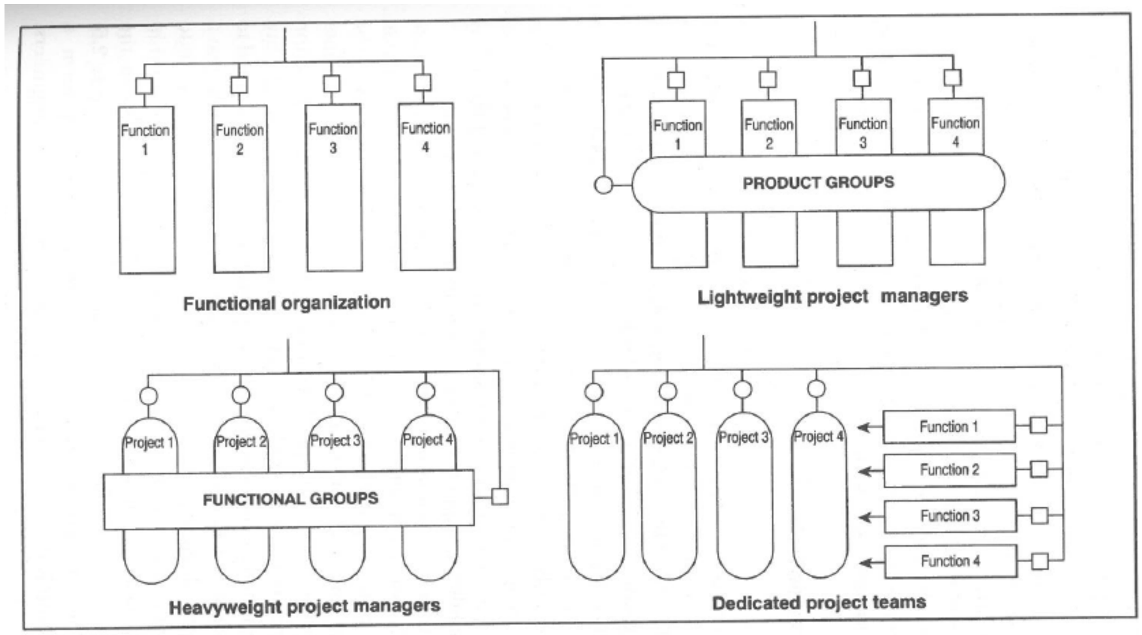

Figure 4. The Four Basic Structures for Management (from Backhouse 1996)

As reported by Ranky, "Rolls Royce Motor Limited has incorporated a transition from traditional or sequential engineering design and manufacturing to parallel, or concurrent and customer driven product creation." Ranky goes on to state: "Driven by completion and cost, Rolls Royce conducted a complete re-evaluation of all activities associate with design, manufacture and support of its automobiles. Although known for high quality and limited production volumes, the same reasons for developing and applying CE included:

Shortened lead times;

Increased productivity;

Products that are:

Very high quality;

Reliable;

Less expensive;

Reflect customers' requirements in a very competitive world market" (Ranky 1994).

D. PROPOSED FUZE DIVISION MANAGEMENT STRUCTURE

This section describes the recommended organizational structure for the Fuze Division, to form a framework that facilitates effective use of CE principles.

1. Defining an Effective Fuze Development Organizational Structure

First, before attempting to lay out an organizational structure, it is important to understand and be able to state the purpose of the organization. Functional analysis and allocation are described as a method to develop a functional block diagram (Blanchard and Fabrycky 1998). A functional decomposition can be used to illustrate all of the functions necessary for an organization to be sufficiently capable to accomplish its given mission.

As shown in Figure 5 the first level includes general functions such as: provide supervisory management and provide engineering expertise in several of the broad disciplines (e.g., mechanical and electrical engineering). Also, at the first level are fuze prototyping and production demo, along with fuze systems engineering. At this point, as noted earlier it would be appropriate to add manufacturing engineering as a first level function.

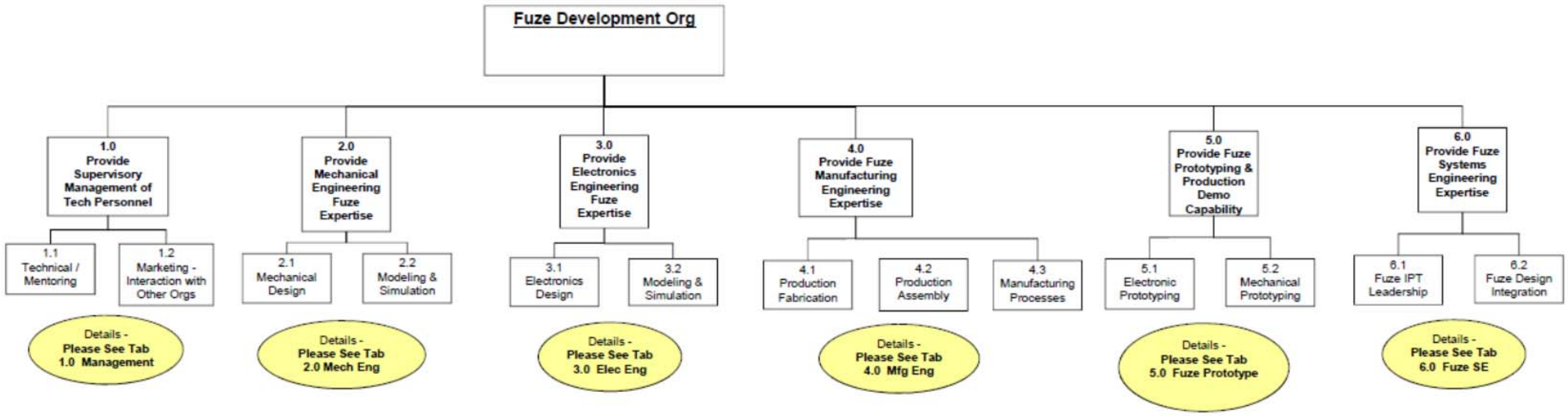

Figure 5. Fuze Development Organization Functional Decomposition Structure

The supervisory management function, although essential, is fairly conventional and well understood and will not be discussed in detail for the purpose of this study. Also, the mechanical and electronics engineering functions are accepted and well-defined, so minimal detail will be explored, other than the approach to group engineers (in their "supervisory management" teams) according to their specialty rather than by fuze/product line, as per current practice.

Based on a review of case studies of firms that have successfully embraced concurrent engineering, most have organized based on the matrix approach. The key factors driving success in the private sector (such as permanent groups of like expertise from which to draw members for project teams) are applicable for use in a government design agency such as the Fuze Division. The (temporary) project-based team approach will provide an environment that will foster the teamwork necessary for effective CE, while the (permanent) functional portion of the structure will allow the Fuze Division to continue to grow and maintain a high level of expertise for all the necessary engineering disciplines.

a. Manufacturing Engineering

The field of manufacturing engineering is of particular interest for this study, because heretofore this field of engineering has not been included within the government organization known as the Fuze Division (or within other groups in government agencies with the mission of developing specialized classes of weapons systems). Although well-established among Industry (both commercial and defense) the field of manufacturing engineering has had minimal or no representation within the government side of fuze development. Reflecting the established "best practices" of Industry, manufacturing engineering will now be deliberately included as a primary function of the proposed fuze development organization in order to identify it as a unique and essential element of good fuze design.

b. Fuze Systems Engineering

The field of systems engineering (SE) is also included as a primary function of the organization for the key role of SE to coordinate engineering from each of the core specialties and bring them together for specific fuze product design efforts. This new Fuze Division organizational structure would include two separate and distinct "management" functions, represented by sections 1.0 and 6.0 as shown on the functional decomposition diagram. As noted above, the supervisory (1.0) function will be focused on personnel management, and maintaining and developing the core competency for each engineering specialty. In addition to classical supervisory tasks, the leaders of this group would ensure that, for example, the mechanical engineering branch has the latest in Computer-Aided Design (CAD) equipment, training and top expertise. For Electronics engineering, ensure appropriate participation in latest RF signal processing research activities, current state of the art electronic components, etc. The systems engineering function (6.0) includes the other management function necessary in a development organization, specifically that of project technical management.

2. Existing Fuze Division Organization Structure

The existing Fuze Division is currently structured to group personnel by general weapon system classes to support fuzing requirements based on the type of weapon. The rationale behind this approach is largely based on historical tradition and probably the fact that support funding is easier to manage at the fuze level, since funding is typically allocated by weapon system and then distributed among all support organizations, fuzing being one. A notional (and intentionally simplified) organizational structure representing the present approach currently in place for the ARDEC Fuze Division is illustrated in Figure 6.

Although manufacturing engineers could be simply added to each of the teams, this would be minimally effective for a government organization that does not inherently possess a manufacturing capability. Establishing a distinct manufacturing engineering team is essential to cultivate a viable core competency that is both effective and accepted by the other design professionals. Additionally, given the fact that this group would be operating at a disadvantage when compared to private companies, because of the lack of actual manufacturing performed directly by the government, the new manufacturing engineering group must devote an ongoing effort to build and maintain the expertise of its members. This would be accomplished by a combination of formal training along with periodic on-site visits to manufacturing facilities of firms that provide components for Defense products such as fuzes.

Intentionally sending Fuze Division's manufacturing engineers out to component producers would help to understand how design decisions could affect manufacturing cost. As presented by Backhouse, the Rolls-Royce Aerospace Group conducted an effort to capture the expertise of component suppliers, and integrate this expertise into their product development routine. To ensure success, much effort was taken to evaluate their (Rolls-Royce's) future requirements, and then identify the best suppliers to build a corporate database of trusted suppliers. From this database, manufacturing experts from the suppliers would be invited to participate in the design process, early enough to contribute significant influence to the design for manufacturing efficiency (after Backhouse 1996).

This confirms Huthwaite's recommendation that management should utilize "show us" statements such as: "show us how you are involving manufacturing and suppliers 'up front' to avoid production problems later. How are you minimizing new tooling and capital equipment?" (Huthwaite 2007).

It would certainly be feasible to cultivate similar relationships between the manufacturing engineering group (Fuze Division) and various vendors and manufacturers with the objective of inviting them to participate in the design of components and assemblies.

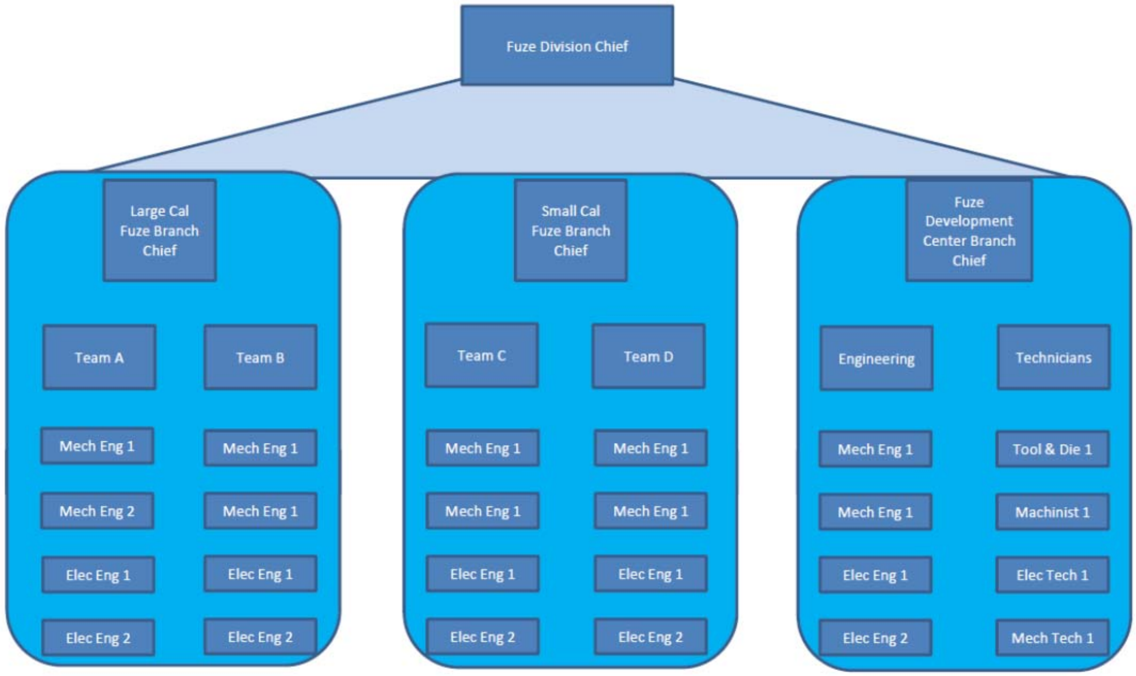

Figure 6. Present ARDEC Fuze Division Organization Structure (Notional)

3. Main Themes–Management and Organization Overview

The management of the Fuze Division would be divided into two main functional roles, supervisory management and project management, which are included as the first two organizational themes, as follows:

a. Supervisory Management

Teams of people would be grouped by field/expertise specialty, forming essentially "permanent" teams, with managers responsible for traditional supervisory roles. Each worker/employee would be a member of only one permanent team, and would remain so regardless of involvement in one or more particular fuze programs.

b. Project Management

Teams of people (drawn from the above-noted permanent teams) would be formed into IPT's to support a specific fuze item. This is a systems engineering approach in that the cross-functional team will work together to develop the product design, coordinating specific elements with the integration of overall customer requirements considered throughout the process. Each IPT will include personnel with expertise appropriate to support the design of a particular fuze throughout the development process. IPT's are "temporary" in nature, to remain in existence only as necessary to support the design of a new (or upgraded) fuze or fuze component. Upon completion of the design, it is likely that the design IPT may be replaced with or transformed into a production engineering IPT. Many times, it is valuable to retain expertise specific personnel with direct development experience on a particular fuze as it moves into production.

c. Manufacturing Engineering

A new manufacturing engineering team would be introduced as a new core competency as a necessary element within the fuze development agency (Fuze Division/FDC).

The Fuze Division currently maintains strong core competencies in various design engineering fields necessary for fuze development (such as electronic and mechanical engineering), and highly specialized niche expertise within those fields, such as digital signal processing, proximity sensor design, micro-electromechanical systems (MEMS), antenna design, etc. However, it is necessary and beneficial to establish and maintain an expertise base in the manufacturing engineering field, with appropriate specialties such as manufacturing processes, like injection molding, sheet metal forming, and automated circuit assembly methods, and perhaps more significantly, concurrent engineering, or the specific consideration of manufacturing processes during the product design process.

d. Design Review Teams

In addition to the two management functions noted above, design review teams will perform a needed part of the development process.

1. Peer review within Fuze Division–the Design Review Teams (DRT) will provide an informal and independent review of fuze projects currently under development.

2. DRTs will review the IPT structure and membership to ensure that IPT makeup is appropriate and sufficient for the type of fuze being developed.

3. DRTs will review the product (fuze) design details, with attention to functional as well as design for production. These design reviews should be planned to occur prior to each of the required formal design reviews such as PDRs, CDRs and Fuze Safety Board reviews. The informal reviews will serve several purposes beyond the basic function of preparing the design (and IPT) for the upcoming formal review. Such "bonus" functions include improving the technical competence of the IPT and also that of the review team, both of which will serve to improve and broaden the overall core competency of the Fuze Division as a whole.

e. Manufacturing Engineering as a Performance Requirement

In addition to the establishment of a new team, manufacturing engineering (or Concurrent Engineering) will be introduced as a performance requirement for fuzes, with equal value or weight as the more traditional "mission" performance requirements and objectives.

4. Proposed Fuze Division Organization Structure

The Proposed Fuze Division organizational structure is laid out to follow and support the functional decomposition discussed earlier. As shown in Figure 7, the division chief is responsible for the entire organization, with branch chiefs each responsible for teams of engineers, grouped according to engineering discipline and their area of specialized expertise. The relationship between the branch chiefs and the division chief is fairly common in terms of fulfilling necessary supervisory functions.

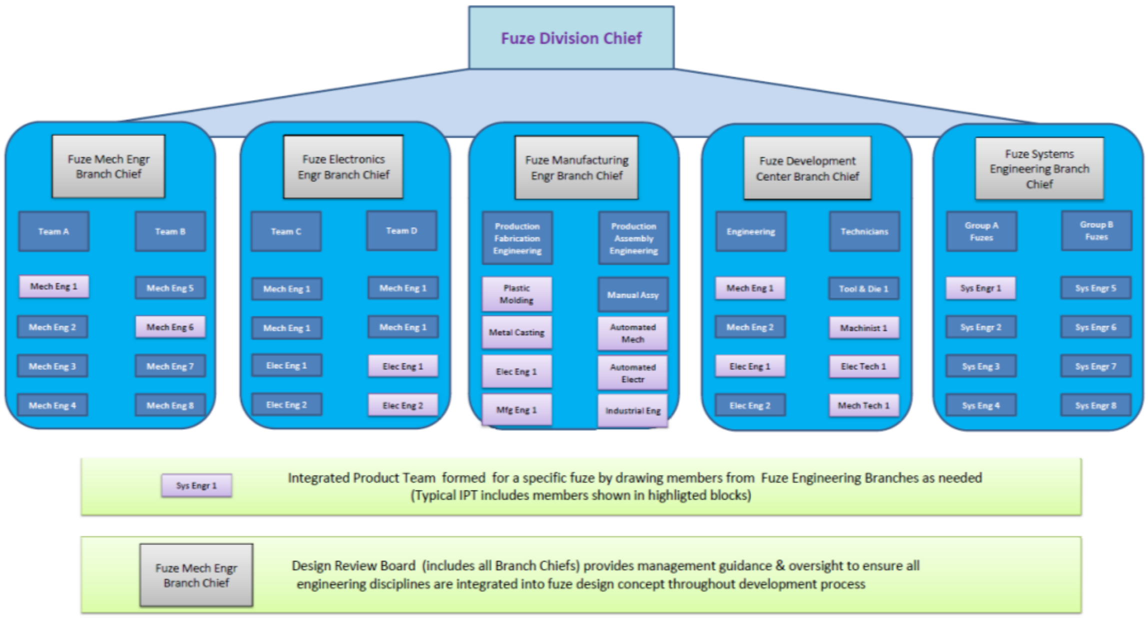

Figure 7. Proposed ARDEC Fuze Division Organization Structure

At this point, it is noted that both the existing and proposed organizational structures presented here in terms of structure and exact fields of expertise have been simplified and also generalized for the purpose of this study and do not necessarily reflect actual conditions or capabilities of the ARDEC Fuze Division. It is further noted that the ARDEC Fuze Division also includes several additional groups that are engaged in advanced research and development for future fuzing technology, which are not discussed here, or included in the proposed organizational structure, to avoid detracting from the focus of this effort on manufacturing engineering.

Within each branch, it is expected that the branch chief would ensure development of his/her particular group, to continually grow the core competency within that particular specialty. Within a branch, each person would typically be assigned to serve on one or more Integrated Product Teams (IPTs) for a particular fuze/product development, with the added benefit of collaboration with other “like-minded” engineers within the group (branch) as needed.

The Fuze Division would include two groups performing separate but related management functions. First, as noted before, would be the supervisor group, which would include all branch chiefs. The second would be the systems engineering group, which would provide a project management role or more specifically, a project technical management role, and from this group would be provided IPT leaders for specific fuze programs. Individual SEs would be under a SE branch chief. Individual SEs would be responsible to lead IPTs formed in a matrix manner where needed engineers would be drawn from their various specialty groups. A benefit of grouping all the SE IPT leaders in one team is that changing needs of each IPT could be met by IPT leaders regular interaction among each other. Also, all the SE IPT leaders would benefit from real-time immediate sharing of ongoing IPT activities and lessons learned.

In addition to IPTs for specific fuze programs, another function to be served though cross-functional teaming would be that of peer design review. A secondary role for the branch chiefs would be to form a design review team, for the purpose of providing periodic, independent review and feedback for all fuze development programs. This would serve as a preliminary checkpoint, to help prepare for required reviews by established safety boards, such as the Army Fuze Safety Review Board. Also, the design review team would ensure that all necessary branches are represented on each of the fuze IPTs.

a. Engineering Branches

Mechanical and Electronic engineering branches would include sub-groups as needed to fulfill specific needs for highly specialized expertise (such as MEMS, proximity sensor design, etc.).

The Manufacturing Engineering branch would be a new addition to the Fuze Division. As noted earlier, the field of manufacturing engineering has found little to no representation in the phases of fuze development normally performed by government agencies. As a new group, the manufacturing engineering branch chief would be responsible to build a core of manufacturing engineers, with a specific focus on fuzing. The manufacturing engineering branch would include mechanical and electronic engineers who understand mechanical and electronic assembly equipment and processes. It is expected that some percentage of overhead type time would include extensive interaction with Industry, since the government does not directly own much in the way of manufacturing capability other than ammunition loading plants. It is significant to note that there is currently no manufacturing engineering expertise, particularly at the management level. As such, a key recommendation would be to seek out and hire an individual with a strong background in manufacturing to serve as the branch chief for the (proposed) manufacturing engineering branch. In addition to being responsible for establishing and maintaining the core competency, this individual would hold responsibility during gate reviews to ensure manufacturability of each fuze product.

A diagram showing the interaction of a new Manufacturing Engineering branch is shown in Figure 8. In order to be successful, this manufacturing engineering group must include intentional interaction with a variety of firms involved in manufacturing of fuzes, fuzing components and related products.

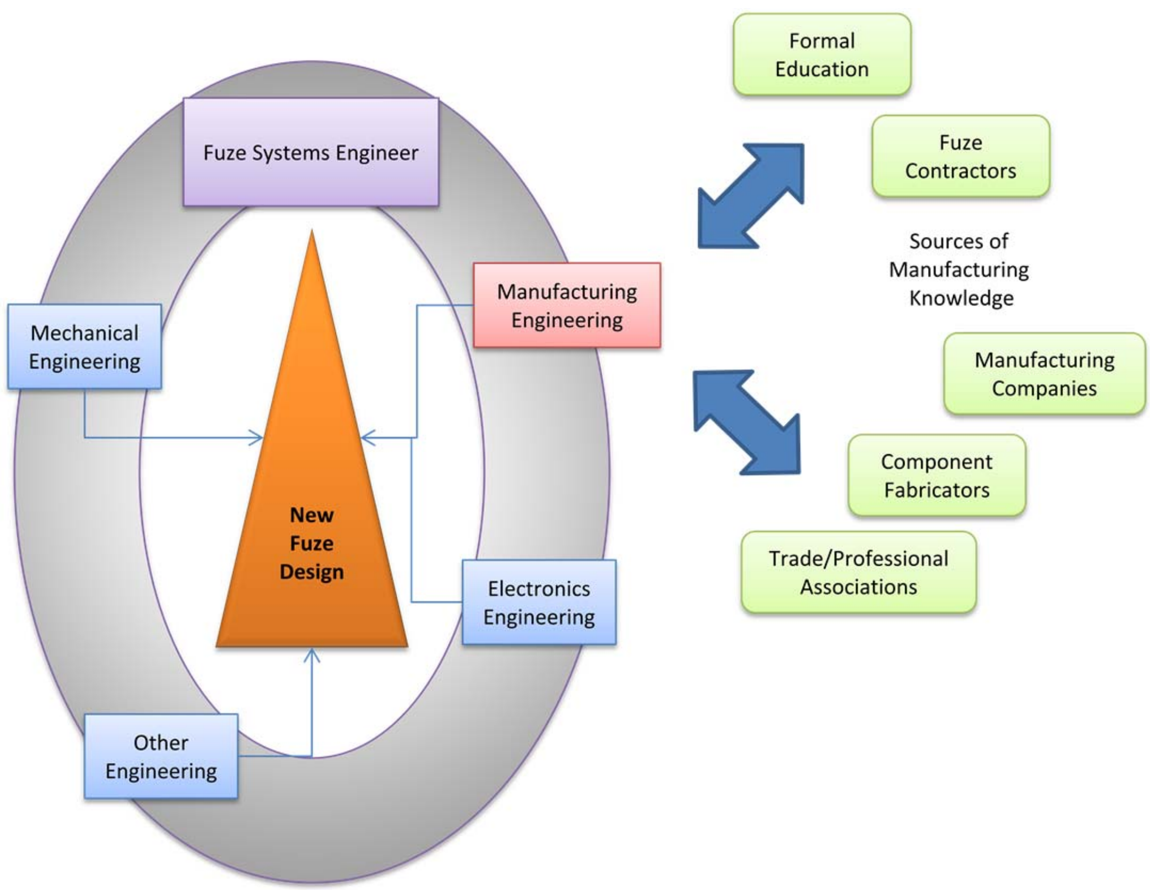

Figure 8. Proposed Manufacturing Engineering Branch Role

At this point it should be noted that due to the limitations imposed by “approved” government job descriptions (engineering series, grade, etc.) and established personnel allocations, it may not be practical to hire manufacturing engineers. Instead, the likely approach to fill these positions would be to find mechanical, electronics and industrial engineers with an interest in manufacturing and engage in a deliberate effort to develop these people into manufacturing engineers. In order to develop a capable core competency in fuze manufacturing engineering, it will be necessary to develop specialized expertise in the following areas essential to fuzing:

Injection molding/casting

Metal forming and stamping

Automated assembly (electronic circuits and mechanical components)

Specialized assembly applicable to fuzing (MEMS, safe and arm assembly)

Anderson describes Honda’s approach to provide in-depth introduction of new engineers to their manufacturing process as follows:

> At Honda, all entry-level engineers spend their first three months in the company working on the assembly line. They’re then rotated to the marketing department for the next three months. They spend the next year rotating through the engineering departments–drive train, body, chassis, and process machinery. Finally, after they have been exposed to the entire range of activities involved in designing and making a car, they are ready for an assignment to an engineering specialty, perhaps in the engine department. (Anderson 2010)

In contrast, entry-level engineers typically begin their careers in government with an extensive series of training classes, with emphasis on learning procedures such as dimensioning and tolerances standards for government drawings, along with some limited hands-on exposure to the handling and operation of weapon systems. However, there is little to no formal approach to familiarize new engineers with manufacturing processes used to produce the weapon systems they will be designing. This is largely due to the fact that almost all weapon systems and components are manufactured by defense contractors and the (unfortunate) perception that it is best to leave all manufacturability issues to those firms, and allow the government engineers to simply focus on design activities.

b. Design for Production–Anew "Performance Requirement"

Within the Fuze Division, the "permanent" structure includes branch chiefs. In addition to their supervisory roles, a Fuze Design Review Board (FDRB) would be established to provide a framework from which to conduct periodic reviews of all ongoing design activities within the Fuze Division. The primary function of the FDRB, which consists of all the branch chiefs, will be to provide structured, regularly-scheduled "gate reviews" for all design/development work being conducted by project-specific IPTs. These reviews will initially establish design requirements, and then provide periodic feedback to IPTs to ensure all engineering specialties are represented, and being applied appropriately. Given that the primary purpose of the proposed new organizational structure is to assure the manufacturability of new fuze designs, the gate reviews should focus on manufacturability. In order to do this, the review team must include manufacturing expertise and currently none of the branch chiefs have this expertise. Therefore, the new manufacturing engineering branch chief will have the role of leading the manufacturability element of each gate review.

Also, the FDRB members will also interact with project management offices to develop complete and appropriate design criteria for new fuze programs as they emerge. Criteria would include normal fuze mission requirements (such as launch environments, tactical operational requirements, etc.). In addition, a key goal of the FDRB will be to promote the value of good manufacturing engineering and advocate early insertion of manufacturing engineering requirements directly into preliminary design criteria. As such, the new manufacturing engineering branch chief would be expected to interact with the executive organizations responsible for developing design criteria for new programs.

The currently prevailing JCIDS policy has been developed by the Department of Defense with the objective of streamlining the overall development process for complex weapon systems. In doing so, the focus on zeroing in on a final design configuration as soon as possible actually tends to eliminate design flexibility too early, which inhibits the effective use of CE practices. Because of the focus on operational performance in early stages, the eventual manufacturing processes to be used in production are essentially ignored. Once a design concept is successfully demonstrated, a milestone decision is then made for approval to begin the next phase of design, and is typically accompanied by some degree of a design freeze, at least with regard to basic functional configuration. This is usually the first opportunity to evaluate appropriate manufacturing processes, which is typically part of some sort of “producibility study” in which the design is allowed to be “tweaked” but not significantly altered at the risk of invalidating any of the preceding functional testing. This inherent weakness in the JCIDS system can essentially render most high-payoff manufacturability-driven design improvements “off limits” if significant design configuration changes are needed.

Regardless, the JCIDS process is accepted, well-established and is unlikely to be changed very soon. However, within a developmental agency such as the Fuze Division it is certainly possible to consider establishing a manufacturing engineering review board to serve as an independent design review to force (or, more preferably, encourage in a positive manner) the design IPTs to intentionally think about manufacturing processes early enough to drive the design. Such a board would help move toward the goal of actually designing a new item from the ground-up for production rather than adapting (force-fitting) an existing design concept into a producible product later.

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IV. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The principle of “design for manufacturing” is proven and generally accepted throughout industry. Most manufacturing businesses are fully committed to the approach and have streamlined their product development processes to leverage the initial investment into substantial value derived from successful and highly producible designs being available to the market quicker. Within the domain of government defense development agencies including the U.S. Army ARDEC Fuze Division, the normal order of operations remains locked into an extensive, serial sequence of discrete incremental steps. Although the established policy is based on good intentions of controlling expenditures on new products yet to be demonstrated, the present system drives every new development program to be managed with a “science project” approach in which the primary (or only) goal is to demonstrate proper function of the developmental item. At the same time, there is a push to determine a “material solution” very early in the overall process, while “production prototypes” are not required until well after the design concept has been locked in. This builds in a restrictive boundary when the time comes for producibility studies and production engineering. At this point production engineering is limited to the extent that the chosen “proven” design can be tweaked to improve producibility, but it is no longer cost-effective to consider any “unproven” (high-risk) alternative designs which might have improved production efficiencies by an order of magnitude.

Although the current defense system development policy is likely to remain unaltered, it is still possible to significantly improve the efficiency of the development process by deliberately introducing manufacturing engineering into the early stages of the design process. For highly specialized items such as fuzes, the structure of the responsible organization (ARDEC Fuze Division) can be designed to facilitate the use of manufacturing engineering as a regular and integral part of the product (fuze) development process.

B. CONCLUSIONS

The research questions identified earlier are addressed as follows:

- What organizational structure(s) have been used successfully by private sector manufacturing firms?

Many firms have successfully reorganized to enhance their use of CE practices. Most have used some variation of matrix management structures to effectively balance their core competencies with the needs of individual design projects.

- For a government design and development organization, how can an organizational structure be designed to deliberately promote the integration of manufacturing into the product development process?

For a government development agency such as the ARDEC Fuze Division, the organization can be restructured using many of the principles learned from Industry. Utilizing the recognized benefits of the matrix management structure, the grouping of core specialties, along with the establishment of a manufacturing engineering group will provide a framework from which to develop and maintain an awareness of manufacturability among all design activities within the organization.

- What does the proposed organizational structure look like? How does it improve upon the established organizational structure?

The ARDEC Fuze Division is currently structured to support fuzes according to functional groupings of the end item (e.g., mortar fuzes, artillery fuzes). A more effective approach to improve the overall quality of fuze designs would be to assign technical personnel to home groups according to their specific engineering discipline (e.g., electronic engineers in one group, mechanical engineers in another). These home groups would fulfill personnel management and supervisory requirements and would also foster professional development by keeping similarly skilled people together.

C. KEY POINTS AND RECOMMENDATIONS

The ARDEC Fuze Division is currently structured to support fuzes according to functional groupings of the end item (e.g., mortar fuzes, artillery fuzes). A more effective approach to improve the overall quality of fuze designs would be to assign technical personnel to home groups according to their specific engineering discipline (e.g., electronic engineers in one group, mechanical engineers in another). These home groups would fulfill personnel management and supervisory requirements and would also foster professional development by keeping similarly skilled people together.

Recommend establishing a team of Fuze system engineers, organized as another home group as described above, with each system engineer to be assigned a project technical management role to lead the development effort for a given fuze program, through IPTs formed with members from each of the specialized home groups as appropriate.

Recommend establishing a team of manufacturing engineers, as another home group, to introduce a new core competency within the ARDEC Fuze Division. As a member of a fuze development IPT, the manufacturing engineer would be responsible to ensure that manufacturing fabrication and assembly processes are considered at all phases throughout the fuze design process. Since government agencies such as ARDEC are not generally involved in manufacturing other than observing and managing production at various contractor facilities, establishing and maintaining a credible team of manufacturing engineers will be a challenge for an organization such at the Fuze Division. Deliberate measures including formal education, frequent active participation in government—Industry partnerships and manufacturing trade organizations will be necessary to ensure the successful development of this key area of expertise. In the case of ARDEC, however, the Fuze Development Center currently includes some key manufacturing capabilities, which will provide an excellent resource to coordinate with and develop the manufacturing engineering group.

Recommend the formation of a design review board, which would comprise all of the branch chiefs. The design review board would review each fuze design on a regular basis, to ensure all appropriate engineering disciplines are integrated into the design process and also serve as a preliminary review to prepare the team for required formal reviews by safety boards.

The upper management (division and branch chiefs) would be expected to interface with Project Management Offices on a regular basis to assist in the development of fuze requirements documentation. In addition to ensuring that expected fuze performance requirements are defined appropriately, the Fuze Division management would promote the value of early inclusion of manufacturing engineering into all fuze design programs. Whenever possible, manufacturing processes should be included along with mission-related performance characteristics, to be considered in trade studies at all milestone design review points. This is an example of working within the limits of the established policy to inject manufacturing design considerations earlier into the development process.

D. AREAS TO CONDUCT FURTHER RESEARCH

It would be of interest to determine the level of excellence from which a government agency such as ARDEC could expect from a manufacturing engineering group with limited direct exposure to actual manufacturing and production of fuzes.

Introduce a "marketing" or "business development" type of role into the Fuze Division. It is evident that among the private sector, the more successful firms have included the customer into the early design phases, either through direct involvement or at least by including marketing type personnel who presumably have insight into the demands of the customer base.

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